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THE MANUFACTURING RESEARCH
CORPORATION OF ONTARIO

1991-92 Report



Ontario Centres of Excellence

MISSION STATEMENT

 The Manufacturing Research Corporation of Ontario (MRCO) supports industrial innovation in Ontario by facilitating the timely and effective transfer of technological advances from the research community to the manufacturing sector.

MRCO directly funds and manages fundamental research at Ontario universities. The corporation sponsors research projects which are relevant to industrial needs. MRCO also helps manufacturers find research expertise to develop applied technology solutions to manufacturing problems.

Innovations in advanced technology are required to ensure the future competitiveness of Ontario manufacturers in international markets. By bridging the gaps between manufacturers and the research community, MRCO contributes to the development of an innovative, R&D-driven, industrial culture in Ontario.

VOCATION DE LA SOCIÉTÉ

 La Société de Recherche Manufacturière de l'Ontario (SRMO) appuie toute innovation industrielle dans la province en facilitant de façon efficace et opportune le transfert à l'industrie manufacturière de tout progrès technologique réalisé par la communauté des chercheurs.

SRMO finance directement et gère la recherche de base effectuée dans les universités ontariennes. La Société finance aussi des projets de recherche ayant trait aux besoins de l'industrie. SRMO aide enfin les manufacturiers à trouver des experts-chercheurs pouvant apporter des solutions technologiques aux problèmes de l'industrie manufacturière.

Les innovations dans la technologie avancée sont nécessaires si l'on veut qu'à l'avenir les fabricants ontariens soient concurrentiels sur les marchés internationaux. En comblant le fossé qui existe entre les manufacturiers et la communauté des chercheurs, SRMO contribue à l'essor d'une culture industrielle vouée à la recherche et au développement.

**Front Cover;****Top**

Spot welding at General Motors in Oshawa, Ontario.

Middle

Processing of plastics by novel extrusion techniques will greatly increase the strength of such materials. Professor Ray Woodhams, an MRCO/OCMR (Ontario Centres for Materials Research) researcher, is shown with prototype extrusion equipment.

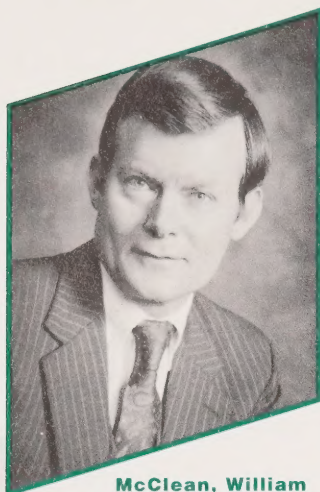
Bottom

At the plant of an MRCO client, a robot inserts odd-shaped components into a printed circuit board.

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CHAIRMAN'S REPORT



McClellan, William

The Manufacturing Research Corporation of Ontario (MRCO) completed its fourth successful year of operation. MRCO, one of the seven Centres of Excellence supported by the Ontario Technology Fund, continues to promote Ontario's industrial competitiveness by supporting world-class, industry-relevant research and by enhancing industry's awareness of the benefits inherent in the commercialization of this research.

MRCO experienced numerous changes in its governing body for the 1991/92 fiscal year. September 1991 marked the retirement of MRCO's founding President, Mr. Edward Dyson. The Board sincerely thanks Mr. Dyson for his wisdom and guidance over the past several years. Mr. Dyson is succeeded by Dr. Grant Allan, who brings to MRCO a wealth of experience in both research and business management. Dr. Allan's ability and eagerness to strengthen MRCO's capabilities as a technology transfer company are welcomed.

Mr. John Urbanic completed his term as Chairman of the Board of Directors. The Board appreciates Mr. Urbanic's direction and dedication over the past four years and is pleased that he will remain an active Board member. Mr. Stephen Van Houten, President of the Canadian Manufacturers' Association, has been selected to join the Board and will replace Mr. Fred Beaman. The Board welcomes Mr. Van Houten and gratefully acknowledges Mr. Beaman's participation over the past several years. A complete listing of the Board of Directors is noted at the end of this report.

RAPPORT DU PRÉSIDENT DU CONSEIL

La Manufacturing Research Corporation of Ontario (MRCO) vient de terminer sa quatrième année d'existence. La MRCO, un des sept centres d'excellence financés par le Fonds de technologie de l'Ontario, continue de promouvoir la compétitivité de l'Ontario en soutenant des projets de recherche que répondent aux besoins de l'industrie et en renseignant les intéressés sur les bienfaits de la commercialisation de la recherche.

Plusieurs changements ont été apportés à la direction de la MRCO au cours de l'année financière 1991-1992. Le mois de septembre 1991 a été marqué par la retraite du président fondateur de la MRCO, M. Edward Dyson. Le conseil remercie sincèrement M. Dyson pour sa sagesse et ses conseils au cours des dernières années. M. Grant Allan a succédé à M. Dyson. M. Allan enrichit la MRCO de sa vaste expérience en recherche aussi bien qu'en administration des affaires. Sa capacité et sa volonté de rehausser la compétence de la MRCO en tant qu'entreprise de transfert technologique sont les bienvenues.

M. John Urbanic a terminé son mandat à titre de président du conseil d'administration. Le conseil tient donc à remercier M. Urbanic pour sa direction et son dévouement durant les quatre dernières années et est heureux de savoir qu'il demeurera en qualité de membre actif du conseil. M. Stephen Van Houten, président de l'association des manufacturiers canadiens, a succédé à M. Fred Beaman. Ainsi, le conseil souhaite la bienvenue à M. Van Houten et aimerait exprimer sa gratitude à M. Beaman pour sa participation et les conseils qu'il a fournis au cours des dernières années. Vous trouverez la liste complète des membres du conseil d'administration à la fin de ce rapport.

Un des principaux programmes de la MRCO, c'est-à-dire l'organisation et la promotion de la recherche dans les domaines les plus susceptibles de profiter aux manufacturiers de l'Ontario, remporte toujours beaucoup de succès. Les projets parrainés par la MRCO ont déjà contribué à l'échange de connaissances entre des universités et des manufacturiers ontariens. En outre, la MRCO prévoit que beaucoup nouvelles technologies pourront être commercialisées dans un proche avenir. L'activité industrielle du centre vise encore les deux

One of MRCO's primary programs, to identify and promote research in fields most likely to produce benefits to Ontario's manufacturers, continues to flourish. MRCO-sponsored projects have already contributed to the transfer of knowledge from Ontario's universities to manufacturers. Additionally, MRCO anticipates that several new technologies will be commercialized in the near future.

The Centre's industrial activity continues to have two overriding objectives: networking an increasing number of manufacturers with researchers in the academic community and expanding the financial base available for industrial research at Ontario universities. The industrial participation section of this annual report will provide further details of MRCO's industrial programs: consortia and technology transfer.

MRCO believes that, as a result of its initiatives, Ontario manufacturers have increasingly come to accept technology transfer as an important factor for economic success and that these manufacturers are more willing to become participants in the process. The Board, as well as the Province of Ontario, affirms this belief.

It was recently announced by the Honourable Ed Philip and the Honourable Richard Allen that funding for the Centres of Excellence program was extended until December 1997. The Board of Directors of the Manufacturing Research Corporation of Ontario would like to thank the Provincial Government for helping to foster competitive development in the province, and for demonstrating a commitment to technology growth.

mêmes objectifs primordiaux: accroître les communications entre manufacturiers et chercheurs universitaires, et augmenter les fonds destinés à la recherche industrielle dans les universités ontariennes. La section portant sur la participation de l'industrie dans le dernier rapport annuel donnera plus de détails sur les programmes industriels de la MRCO: les consortiums et le transfert de technologie.

La MRCO croit que ces mesures ont fait en sorte que les manufacturiers ontariens se rendent de plus en plus compte que le transfert de technologie influence grandement leur succès et qu'ils sont ainsi mieux disposés à participer à ce processus. Le conseil d'administration ainsi que la province de l'Ontario abondent dans le même sens.

L'honorable Ed Philip et l'honorable Richard Allen ont récemment annoncé que le financement du programme de centres d'excellence était prolongé jusqu'en décembre 1997. Le conseil d'administration de la Manufacturing Research Corporation of Ontario désire remercier le gouvernement provincial pour ses efforts visant à accroître la compétitivité de la province et pour son engagement envers le développement de la technologie.



McClean, William
Chairman - MRCO

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PRESIDENT'S REPORT



Allan, Grant

The Manufacturing Research Corporation of Ontario continues to aggressively pursue the vital mandate of promoting advanced manufacturing research and development projects at Ontario universities and of facilitating the transfer of technological advances from the research community to the manufacturing sector.

Post-secondary institutions must produce appropriate, world-class technology that can be transferred to Ontario industry. At the same time, there must be recipients for technological advances in the manufacturing sector. Accordingly, one of MRCO's major objectives over the past four years has been to increase industrial participation in university-based research. MRCO's success in this area reinforces its expertise as a technology transfer agent.

Receptor-driven technology is a key element of the transfer process and this is fundamental to MRCO's present and future research funding strategies. In addition to the successful commercialization of two MRCO research projects, the program has generated a number of other technologies which are expected to be commercialized in the very near future.

MRCO's Industrial Participation Program focuses on two main thrusts: Consortia and Technology Transfer. The highly successful Consortia Program identifies opportunities for the development of research-based solutions to technological problems common to groups of manufacturers. In anticipation of a well-defined pay-off, manufacturers provide either cash or in-kind contributions to support the appropriate research expertise sourced by MRCO's professional staff.

RAPPORT DU PRÉSIDENT

La Manufacturing Research Corporation of Ontario (MRCO) poursuit toujours aussi énergiquement sa mission vitale de promouvoir les projets de recherche et de développement avancés en fabrication auprès des universités de l'Ontario et de faciliter le transfert des progrès technologiques de la communauté de recherche au secteur manufacturier.

Les établissements d'enseignement post-secondaires doivent mettre au point des technologies de premier ordre que peuvent être utilisées par l'industrie ontarienne. Cependant, il faut que le secteur manufacturier compte des entreprises prêtes à mettre à profit ces progrès technologiques. En conséquence, un des principaux objectifs de la MRCO au cours des quatre dernières années a été d'augmenter la participation de l'industrie dans la recherche universitaire. Le succès que remporte la MRCO à ce chapitre consolide son rôle d'agent de transfert technologique.

Par ailleurs, la technologie développée sous la direction d'entreprises demanderesse favorise considérablement le processus de transfert, ce qui est fondamental pour les stratégies actuelles et futures de financement de la MRCO. Outre la commercialisation fructueuse de deux projets de recherche de la MRCO, le programme a produit d'autres technologies qui devraient être commercialisées dans un très proche avenir.

Le programme de participation industrielle de la MRCO vise deux buts principaux: les consortiums et le transfert technologique. Le programme de consortiums, qui remporte beaucoup des succès, identifie des possibilités de développer par la recherche des solutions pour traiter des problèmes technologiques particuliers à certains groupes de manufacturiers. Lorsqu'ils prévoient retirer des avantages clairement définis, les manufacturiers fournissent soit de l'argent soit des ressources pour appuyer les chercheurs et chercheuses qui sont recrutés par le personnel professionnel de la MRCO.

Le programme de transfert technologique fournit activement des innovations en recherche et leur application dans un environnement industriel donné. Les intervenants clés dans le processus de transfert technologique, tels que les établissements d'enseignement post-secondaires et les manufacturiers, peuvent tous profiter d'une alliance stratégique efficace. La MRCO continuera de travailler avec les universités, les chercheurs et chercheuses et les organismes d'accréditation afin de maximiser la commercialisation de la technologie.

The Technology Transfer Program encompasses the active sourcing of research innovations and their application to an industrial setting. Key players in the technology transfer process, such as post-secondary institutions and manufacturers, can mutually benefit from an effective strategic alliance. MRCO will continue to work with universities, researchers and licensees to maximize the successful commercialization of technology.

At the international level, MRCO continues to assist in the co-operative Baden-Württemberg Project. Funded jointly by the German province of Baden-Württemberg and the Province of Ontario, this project seeks to integrate computer-aided process planning with production planning and control.

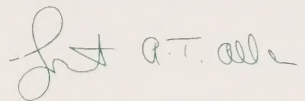
In 1991, Mr. Bill McClean, Vice President of Manufacturing and Development at IBM Canada Limited, succeeded Mr. John Urbanic, Director of Car and Truck Assembly Operations at General Motors of Canada Limited, as MRCO's Chairman of the Board of Directors. The Board, as well as the Senior Advisory Committee (SAC), provided valuable assistance to MRCO management in the 1991/92 operating year. The Finance Committee assisted the Board by examining and monitoring all quarterly financial statements; the Executive Committee met as necessary, at the discretion of the Board, to address crucial issues. A list of members of these committees may be found in the Review of Operations section of this report.

MRCO has played, and will continue to play, a vital and significant role in the economic renewal of the Province of Ontario. The imperativeness of global competitiveness and on-going economic restructuring continue to grow as the Centre approaches its fifth year of operation. MRCO is positioning itself as a world-class organization with proven experience and expertise in converting technology from the laboratories of the province's academic institutions into the creation of jobs and wealth in the manufacturing sector of Ontario.

À l'échelle internationale, la MRCO continue de contribuer au projet coopératif Baden-Württemberg. Fondé conjointement par la province allemande de Baden-Württemberg et l'Ontario, ce projet a pour but d'intégrer la planification de processus assistée par ordinateur à la planification et au contrôle de production.

En 1991, M. Bill McClean, vice-président à la fabrication et au développement d'IBM Canada Ltée, a succédé à M. John Urbanic, directeur des activités d'assemblage de voitures et de camions chez General Motors du Canada Ltée, à titre de président du conseil d'administration de la MRCO. Le conseil d'administration ainsi que le comité consultatif ont fourni une précieuse aide à la direction de la MRCO au cours de l'année 1991-1992. Le comité des finances a également secondé le conseil en examinant et en contrôlant tous les états financiers trimestriels; quant au comité exécutif, il se réunit, au besoin et à la discrétion du conseil, pour discuter de questions cruciales. Vous trouverez la liste des membres de ces comités dans la section <<Review of Operations>> de ce rapport.

La MRCO a joué et jouera un rôle important et vital dans le renouveau économique de l'Ontario. À l'aube du cinquième anniversaire de la création du centre, les impératifs de la compétitivité globale et la restructuration permanente de l'économie continuent de prendre de l'ampleur. La MRCO joue de plus en plus un rôle de leader à l'échelle internationale grâce à son expérience et à son expertise éprouvées que lui permettent d'utiliser la technologie issue des laboratoires de établissements d'enseignement de la province pour créer emplois et prospérité dans le secteur manufacturier de l'Ontario.



Allan, Grant
President - MRCO

REVIEW OF

OPERATIONS

UNIVERSITY RESEARCH PROGRAM

The Centre continues to support industry-relevant research at six Ontario universities. MRCO's principal investigators remain world-class in their respective fields and continue to focus their research on the needs of Ontario manufacturers.

During the 1991/92 fiscal year, 30 principal investigators and 48 associate researchers successfully managed 46 projects. MRCO distributed \$5.6 million in research funding among the following academic institutions: Carleton University, McMaster University, Queen's University, University of Toronto, University of Waterloo and the University of Western Ontario.

MRCO's researchers continue to interact across university lines. Collaborative relationships have developed in MRCO's automation theme between Waterloo and Toronto as well as between Queen's and Waterloo. Productive associations have also developed in fuzzy logic management systems between Toronto and Guelph. MRCO's CAPE project at Waterloo requires direct collaboration between university scientists at Queen's and Toronto. Likewise, MRCO's oriented polymer project at Toronto receives significant input from McMaster. All of these successful relationships were driven by interest and need on the part of the researchers.

The advancement of Ontario's graduate students as a resource continues to be a major product of MRCO's research program: a total of 145 students received financial support during 1991/92.

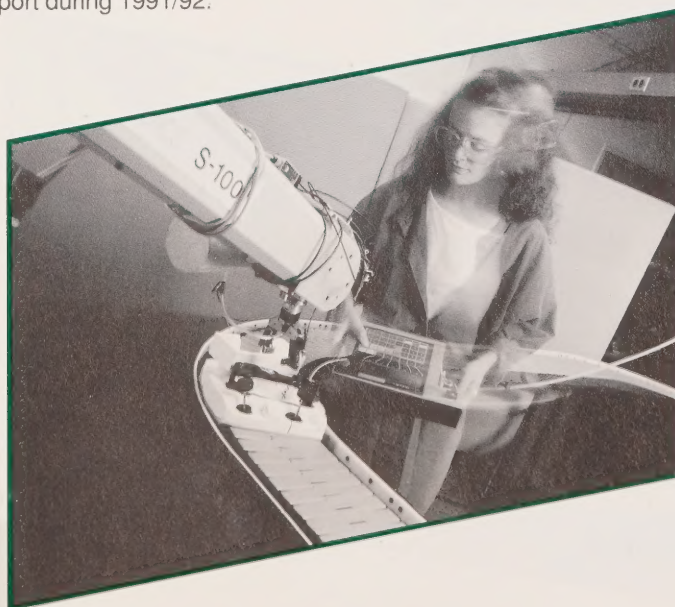
In addition, MRCO supported, in whole or in part, 238 individuals in the following positions: post-doctoral fellows, research assistants, research engineers/technicians, visiting professors and administrative assistants.

It is interesting to note that Federal Government support to MRCO's researchers has increased dramatically since 1990/91. Chart 1 shows an increase of almost \$600,000.

MRCO's investigators continue to reach out internationally. As shown in Chart 2, international collaboration has significantly escalated since 1990/91. These charts may be found in Appendix 3.

In August 1991, two of MRCO's principal investigators were elected to The International College for Production Research (CIRP). This prestigious college examines issues in production engineering; admission is by invitation only and is limited to four members from each participating country. Professor Hoda ElMaraghy, of McMaster University, was elected a chairperson of CIRP's Scientific Technical Committee on Assembly; Professor Robert Fenton, from the University of Toronto, was elected as a member.

MRCO's research program is structured under four theme areas: Automation, Design, Management, and Process. The following section provides examples of research projects currently underway in each area.



Computers are tools that make our lives easier. Engineers experiment with them, enhance them, and apply them to the everyday world.

AUTOMATION

Focus

Automation in product design, process planning and production involves research in leading-edge technologies, such as: Artificial Intelligence, Artificial Neural Networks, Information Technology, Sensors, Robots, CNC and Autonomous Manufacturing Tools. Supporting research in the "automation" area will result in improved productivity, ultimately resulting in lower costs per unit of production.

Highlights

At the University of Toronto the development of a fundamental scientific base for extending the dexterity of robot end effectors is represented in MRCO's project, ***Mechanics and Control of Dexterous Devices***, led by Professor Andrew Goldenberg. To date, end effectors have had little or no flexibility for use in different tasks or in handling a variety of objects.

Several of the more fundamental methods under investigation are based on new concepts such as "Admittance Centre," "Common-Sense Reasoning," and "Impedance Matching". One issue of considerable importance is the shape and layout of devices. In order to render the devices dexterous, it was deemed appropriate to use end effectors consisting of "fingers", representing the human hand. This will aid in the development of alternatives which are less complex to design and control.

In conjunction with the above-mentioned research, industry collaboration has led to the development of hardware and software for new concepts in end effectors for a variety of applications, including

telerobotics for forestry operations, and modular robotic linkages. As well, new applications of control theory for robotic end effectors have been developed and were experimentally tested and applied to industrial projects such as force control for space applications and modern control of mining equipment.

At the University of Toronto, Professors K.C. Smith and B. Benhabib are currently researching the ***Development of a Closed-Loop Supervisory Control System (CLaSiCS)***. This project, directed towards manufacturing workcells, aims at assuring a marked increase in the integration of decision-making systems with production planning and control. This will be accomplished by developing the next generation of intelligent manufacturing management systems for the planning and supervisory control of production in a CIM environment.

The research of Professors Smith and Benhabib focuses on analyzing state-of-the-art technologies, experimenting with them and improving upon them in the following areas: robotic-workcell planning; programming; control-strategy development; short-to-medium range active sensing; and fusion of sensory data.

As a result, a number of programs have been developed and implemented. These include a manufacturing workcell management system, a supervisory control system and a 3-D object recognition program for robotic assembly workcells.



An active vision system for 3D-object recognition in robotic assembly workcells.

Focus

Design in manufacturing involves the integration of analysis software with actual product design. All projects within MRCO's Design Group support design as an integral part of manufacturing. The majority of the projects use software development to resolve design issues such as vibration, stress and systems dynamics.

Highlights

Professor Hoda ElMaraghy, an MRCO researcher at McMaster University, is leading a team working on a **Feature-based Modelling and Design** project. The project's objective is to design and develop a design-by-features system which can capture both geometric and technical knowledge and share this knowledge with subsequent manufacturing task planning.

The underlying concept is to facilitate simultaneous engineering activities and create design tools capable of capturing the designer's intent and functional requirements while, at the same time, making the designer aware of the downstream effect that decisions made at the design stage have on the "manufacturability" of the products.

Professor ElMaraghy's research team has designed and implemented an "Intelligent Product Design and Manufacture (IPDM)" system which uses functional features for modelling and provides a seamless link between design and manufacturing process planning.

Professor Gordon Andrews, an MRCO researcher at the University of Waterloo, is currently working on projects involving computer-aided machine design, in particular, the development of new computer methods for the analysis and design of moving machinery under the project entitled, **Integration of CAD and Kinematic/Dynamic Analysis**. Some of Professor Andrews' research in this field has already been implemented in several Ontario manufacturing plants.

A second project under Professor Andrews' direction involves computer-aided design of "optimum-strength" gear-sets. Standard gear-sets are virtually never optimum; the gear-set is always limited by the weaker gear (usually the pinion). His team has developed a computer program, "WATGEAR," that can carry out the complex strength calculation for any gear-set, and through an iterative process, change the offsets until an optimum gear-set is obtained. In addition, the program can also calculate measurements for metrology checks and can simulate the machining operation on the computer screen to ensure that problems such as undercutting will not occur during manufacturing. The benefits in using this program are significant. Increases in strength of 10 - 20% are typical, with no increase in material, machining or heat-treating costs.



Professor Gordon Andrews surveys a pinion and gear assembly for a small press which was analyzed using the WATGEAR software.

MANAGEMENT

Focus

Management in manufacturing relates to efficient plant management, including inventory control, quality control, material flow, plant lay-out optimization, simulation and scheduling.

Highlights

At the University of Waterloo, MRCO's Professor Jerry Lawless and his team are working on a project entitled, ***Analysis and Control of Warranty Claims and Reliability Problems***. The project's three key topics are: how to design and test for reliability and durability in the product development stage; how to increase the reliability of the processes that produce the product; and how to measure the reliability and performance of the product when used by customers.

Professor Lawless and his group use many sources of information, including experiments run by the manufacturers, manufacturing process data, customer surveys, and data on warranty claims. To date, several of the methods developed by this group have been applied to such diverse products as automobiles, microchips and insulation for high-voltage cables.

Professor Burham Turksen and his team at the University of Toronto have developed several prototype fuzzy expert systems under the project, ***Knowledge-based Management Systems for Integrated Manufacturing***. Fuzzy technology uses modes of reasoning which are approximate rather than exact, which in effect, imitates the human reasoning system.

It has been found that there are two classes of industrial applications where fuzzy expert systems would be beneficial. These are applications in which the marginal cost of information gathering and analysis is larger than the marginal gain in performance, and cases in which the information to be acquired is inherently vague at the source.

All the know-how to create the necessary technology transfer of fuzzy expert systems to Ontarian and Canadian industry has been developed in the MRCO laboratory. Presently, there are plans to implement the fuzzy technologies in an autonomous mobile robot at an Ontario manufacturing plant and in aluminum processing for wheel production at a very large automotive manufacturing plant.



MRCO-Kibsim Lab
at the University of
Toronto.

PROCESS

Focus

Process in manufacturing focuses on new methods of reducing costs in processing technologies for various materials such as chemicals, plastics, polymers and metals.

Highlights

At McMaster University, research work in the field of machine tools and metal cutting is represented by MRCO's project, **Limits, Controls and Optimization for Machining Processes**, directed by Professor M.A. Elbestawi. The purpose of this research is to develop methods for increasing the productivity, utilization and accuracy of numerically controlled machine tools.

Professor Elbestawi's research involves the development of sensing techniques for in-process monitoring and detection of tool conditions such as breakage and wear, as well as control strategies to maximize metal removal rates and minimize machining costs. These strategies are based on expert, knowledge-based systems and adaptive control technologies.

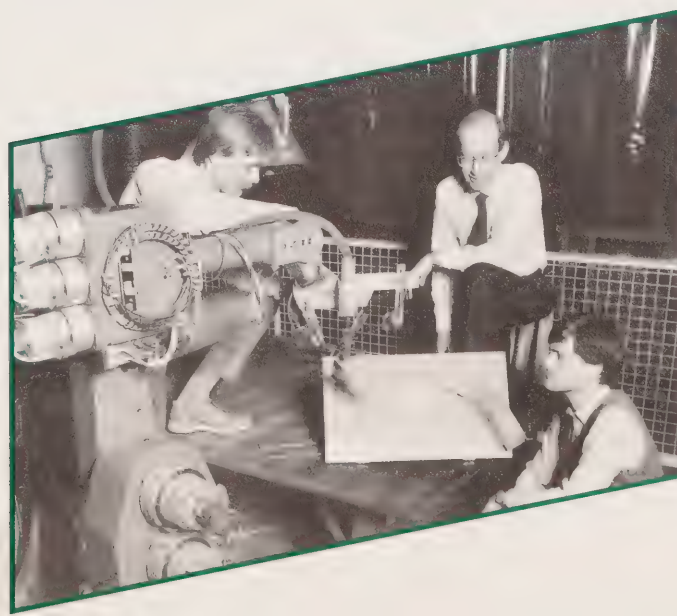
The research group has developed several advanced monitoring systems which are capable of detecting on-line tool failure for various machining processes.

These systems are based on models for cutting mechanics and advanced sensing and signal processing techniques. In addition, sophisticated control systems have been developed to compensate for machining problems and increase machine tool utilization.

Welding is considered an extremely important process in manufacturing. According to a recent survey in *Sheet Metal Welding in the 1990s*, over 50% of the gross national product of industrialized nations involves welding technology.

MRCO's **Welding Automation** project at the University of Waterloo, guided by Professor Hugh Kerr, is directed towards the application of integrated manufacturing technology to improve the production of welded components.

The long-term goal of this project is to produce a system for robotic welding in which the design of the joint to be welded, the control of the welding process, and the positioning of the torch and workpiece during the weld are integral parts of a single system. Toward these goals, research has been carried out in four key areas: object modelling and weld design; numerical modelling of the welding process; modelling and control of welding processes; and robot, sensor and welding process integration.



At the University of Waterloo a Reis robot follows a complicated welding shape. From left to right: Professor Jan Huisson; Professor Hugh Kerr, Project Leader; Professor David Weckman.

INDUSTRIAL PARTICIPATION PROGRAM: CONSORTIA

MRCO currently manages five consortia involving 39 companies. Building consortia involves bringing groups of Ontario manufacturers together and assisting them in pooling their financial and technical resources to develop pre-competitive, research and development based solutions to problems of common interest to the group.

The average corporate commitment to MRCO consortia activities has been almost \$140,000, including cash and in-kind contributions. MRCO's consortia have invested approximately \$6.2-million in R&D projects and have secured an additional \$4.6-million in project funding from various government sources. In this way, MRCO's consortia activities have contributed approximately \$11.0-million to academic R&D in Ontario.

MRCO's ***Manufacturing Behavioural Consortium*** consists of four major Canadian corporations who wish to define and identify the organizational and individual factors responsible for differences in productivity between and within organizations. The project's objective was to develop a model of productivity linking the variables indicating reliable measures of performance with the predictability of situations in which productivity is likely to be high or low. MRCO sourced the expertise of Dr. Bill Jones, a Psychologist at Carleton University. His team reviewed relevant literature on industrial productivity with a particular emphasis on problems of measurement. They concluded that productivity measurement should centre on effectiveness, which relates individual and aggregate output to the goals of the organization.

The study examined differences between two manufacturing groups within the same industry whereby one was deemed to be more productive than the other. The study methodology, which included such tools as interviews, workshops and questionnaires, used a variety of quantitative and qualitative assessments so that differences between groups in aggregate and individual measures of efficiency and effectiveness could be illustrated. Further, differences in work attitudes and in managerial practices, as well as organizational culture, were highlighted.

The project had a duration of six months and led to the development of a Productivity Model which links the variables so that reliable measures of performance can be identified and situations in which productivity is likely to be high or low can be predicted.

The accurate prediction of those variables which may impact on productivity within employee groups is of significant benefit in influencing corporate behaviour towards improved productivity. The successful development of a predictive model allows organizations to utilize the findings of this study in manufacturing, or other settings involving groups of staff involved in value-added activities.

A second and very different project is MRCO's ***Productivity Improvement Consortium***. In 1990, MRCO organized this consortium for a major Canadian corporation and a number of its suppliers. The objective was to reduce costs associated with the process of manufacturing a product by implementing the most appropriate and up-to-date systems in each supplier plant.

Systems considered included just-in-time, manufacturing resources planning, total quality management and integrated manufacturing systems.

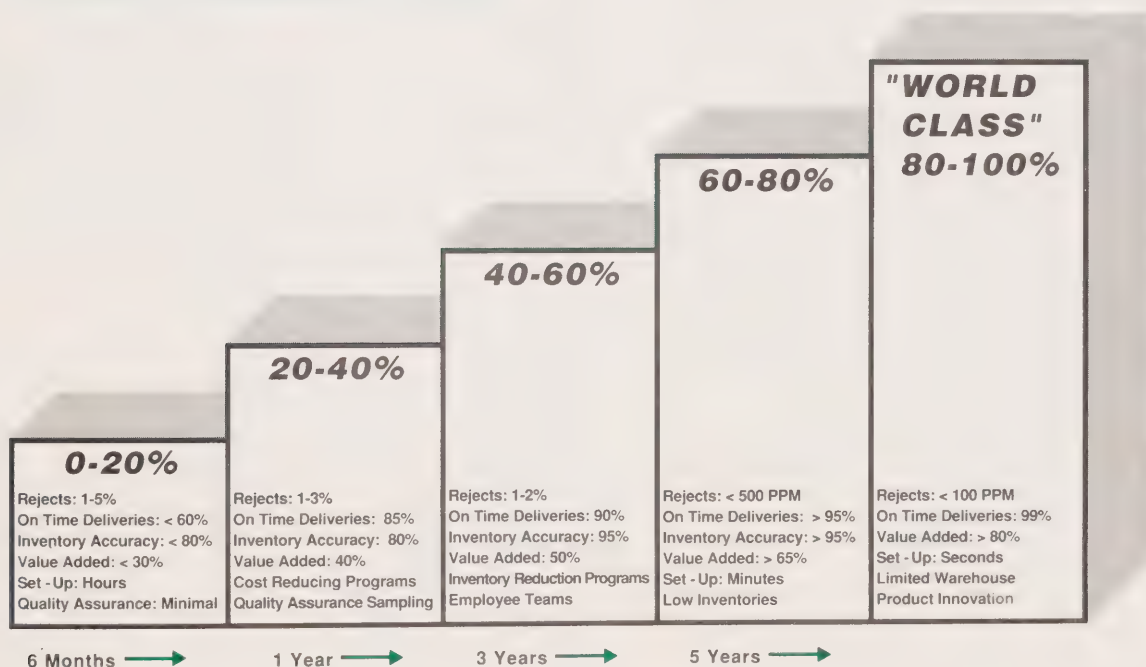
MRCO engaged the services of a consultant to study the day-to-day operations of each organization involved and to make recommendations based on the findings. The members of the consortium then prioritized their needs and decided which projects to undertake.

With the consultant's assistance and the project management expertise of MRCO, significant gains in productivity and reduction of cost have been implemented in each of the members' operations.

The companies have now embraced the concept of continuous improvement and are on their way to becoming world-class organizations.

In future, MRCO intends to increase the effectiveness of its consortia activities by focusing the Centre's efforts on specific target sectors. Furthermore, MRCO's experience shows that successful consortia share three common characteristics. These are clearly defined project objectives and framework, a lead or "champion" company and a membership size small enough to optimize the effectiveness of the consortia efforts. The development of future consortia will incorporate these principal characteristics.

STEPS TO WORLD CLASS



INDUSTRIAL PARTICIPATION PROGRAM: TECHNOLOGY TRANSFER

A major component of the Manufacturing Research Corporation of Ontario's (MRCO) mission is to facilitate the transfer of technological advances from the research community to the manufacturing sector. Over the past four years, the Centre has developed an understanding of the complex process of commercialization of technology and has identified three key elements of this process.

Successful technology transfer relies on organizations who are receptive to the adoption of new processes and products; research driven by the needs of the receptor organization and ongoing involvement of the receptor in the research process; and the availability of effective mechanisms for linking the developer and receptor communities.

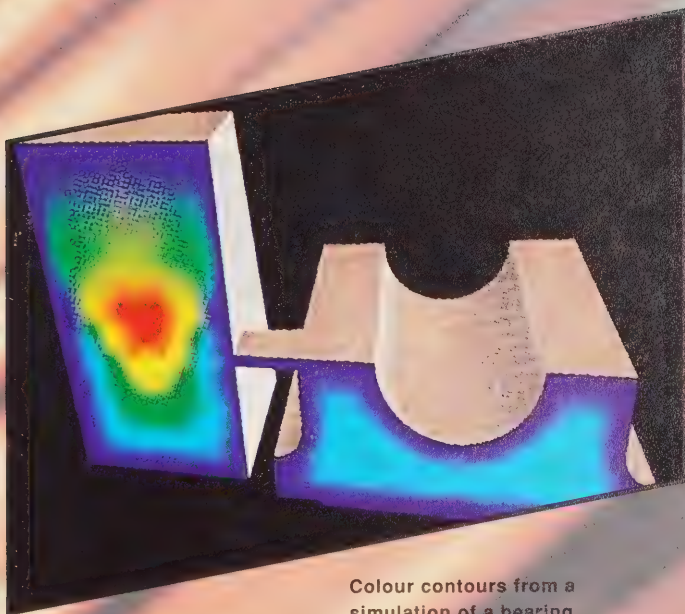
Professor John Goldak's modelling project at Carleton University is an excellent example of research motivated by receptor organizations and the use of an effective mechanism, namely consortia, to link research and development institutions with receptor organizations. The **Canadian Foundry Group Consortium** and the **Canadian Die Cast Consortium** anticipate that the software developed by Dr. Goldak and his associates will enhance productivity, improve quality and reduce costs.

Professor Ray Woodhams' plastic extrusion process is an illustration of technology transfer to companies receptive to the adoption of new, innovative processes and products. Professor Woodhams and his team of researchers at the University of Toronto have designed and constructed an extrusion process by which commercial polymers can be directly extruded into highly oriented profiles having exceptionally high strength.

A large number of applications are possible because of the outstanding mechanical properties and low densities of the self-reinforced plastics created with this new process. The anticipated products range all the way from sheet materials, laminates and packaging film to rigid food containers, automotive components, furniture and electronic goods.

Patent applications for this project have now been filed and a license has been granted for further commercial development to Mr. Won Sung, President of *SRP Industries Ltd. (Self-Reinforced Plastics Industries)*, an Ontario-based company.

MRCO's current research program has also created a number of other technologies which are nearing commercialization. Additionally, the Centre will intensify its efforts to generate receptor-driven technology by reshaping its research portfolio and by further stressing the involvement of industry in the process.



Colour contours from a simulation of a bearing cap casting taken from Professor John Goldak's casting simulation program at Carleton University. When complete this project will produce computer software capable of drastically reducing the time to market for new castings.

The Centres have also developed new trade show display panels, a logo, a research directory and a brochure and are currently involved in exploring other areas of collaboration.

The Manufacturing Research Corporation of Ontario, in conjunction with the Ontario Centre for Materials Research, offers a one-day seminar to high school science teachers showing how fundamental research moves into the marketplace. These highly successful yearly workshops provide teachers with a review of the science fundamentals on which new products are based; an overview of the new science needed to develop them; and an overview of the markets for finished products and processes.

January 1992 marked the opening of the newly renovated Mining Building at the University of Toronto. As one of the original School of Practical Science buildings, the Mining Building has a legacy of active engineering research and education. The renovations to the building were made possible through a partnership of industry, government and academic funding sources. MRCO provided partial funding for the renovations and also devoted time and money to the opening ceremonies. The ceremonies attracted the Honourable Ed Philip, Minister of Industry, Trade and Technology; Mr. Rob Prichard, President of the University of Toronto and Mr. William McClean, Vice President of Manufacturing and Development at IBM and the Chairman of MRCO's Board of Directors.

Several new communication initiatives are planned for the coming fiscal year. MRCO believes that these stimulating ventures will yield valuable dividends by bridging the gaps between manufacturers, the research community, and Ontario's educators.

APPENDIX 1

COMMITTEE MEMBERSHIP

1991/92

SENIOR ADVISORY COMMITTEE

Dr. Derek McCammond

Chairman of Mechanical Engineering
University of Toronto

Mr. Nick K. Befanis

Director, OPS Planning and
Services
Northern Telecom Canada Limited

Dr. Bill Lennox

Professor of Civil Engineering
University of Waterloo

Dr. David R. Henderson

Executive Vice President
MRCO

Dr. Grant Allan

President
MRCO

Dr. Ross Judd

Professor of Mechanical Engineering
McMaster University

Mr. Mike J. Powell

Administrator, Manufacturing
Planning and Sales
General Motors of Canada Limited

Mr. Paul Belluz

Manager, Manufacturing Strategies
IBM Canada Ltd.

Mr. Ed Cinitis

Director, Technology Transfer
MRCO

FINANCE COMMITTEE

Dr. Ron Childs

Vice President Research
McMaster University

Mr. Les C. McLean

Vice President of Quality & Technology
Stelco Inc.

Dr. Clare Beingessner

Vice President of Engineering
B & W Heat Treating (1975) Limited

EXECUTIVE COMMITTEE

Mr. William J. McClean

Vice President of Manufacturing
and Development
IBM Canada Limited

Dr. Ron Childs

Vice President Research
McMaster University

Dr. Clare Beingessner

Vice President of Engineering
B & W Heat Treating (1975) Limited

APPENDIX 2

MANUFACTURING RESEARCH CORPORATION OF ONTARIO

RESEARCH EXPENDITURES REPORT

Year Ended 31/03/92

University	Researcher	Theme	Expenses	Project Title
1) Western	ElMaraghy, W.	Design	\$ 149,000	Design and Analysis for Manufacturing
		TOTAL:	<u>\$ 149,000</u>	
2) McMaster	ElMaraghy, H.	Automation	\$ 238,000	Intelligent & Flexible Automation
		Design	\$ 189,000	Feature-based Modelling/Design
		Design	\$ 76,700	Design Tolerancing
	Elbestawi, M.	Automation	\$ 63,800	Sensor Centre for Indust. Robots
		Process	\$ 301,600	Limits, Control & Optimization of Machining Processes
	Kay, A.	Process	\$ 227,300	Development of Steels with Improved Machinability
	Sowerby, R.	Process	\$ 192,800	Sheet Metal Forming and Ductile Fracture and Wear Mechanisms
	Dokanish, M.	Design	\$ 110,500	Finite Element Analysis of Laminated Fibre Composites
		TOTAL:	<u>\$1,399,700</u>	
3) Queen's	Bayoumi, M.	Automation	\$ 211,900	Perception and Control for Autonomous and Teleoperational Robots
		TOTAL:	<u>\$ 211,900</u>	
4) Carleton	Goldak, J.	Design	\$ 220,900	Feature-based Design of Castings
		TOTAL:	<u>\$ 220,900</u>	

University	Researcher	Theme	Expenses	Project Title
5) Waterloo	Wong, A.	Automation	\$ 368,500	Sensor Knowledge-based Intelligent Manufacturing
	Wilson, W.	Automation	\$ 128,600	Direct End-Point Control of Lightweight Robots Using Integrated Sensors
	Vannelli, A.	Management	\$ 35,300	Optimization-based Approaches for Cellular Manufacturing
	Kerr, H.W.	Process	\$ 213,800	Welding Automation
	Douglas, P.L.	Process	\$ 255,800	Computer Aided Process Engineering
	Schey, J.	Process	\$ 119,200	Tribological Aspect of Metal Forming
	Lawless, J.	Management	\$ 52,600	Analysis/Control of Warranty Claims/Reliability Problems
	Buzacott, J.	Management	\$ 277,300	Planning/Scheduling Under Uncertainty
	Wu, C.F.J.	Management	\$ 62,700	Integrated Models and Data for Manufacturing, Planning, Operation and Control
	Yovanovich, M.	Design	\$ 258,300	Thermo Fluid CAD & Optimization for Integrated Manufacturing
	Andrews, G.	Design	\$ 54,900	Integration of CAD and Kinematic/Dynamic Analysis
TOTAL:			<u>\$1,827,000</u>	

University	Researcher	Theme	Expenses	Project Title
6) Toronto	Davison, E.	Automation	\$ 129,100	Dev. of Control Techniques for Process and Robotic Control
	Smith, K.C.	Automation	\$ 154,000	Sensor Systems Emphasizing Preconditioning
	Fenton, R.	Automation	\$ 79,500	Kinematic and Dynamic Analysis and Performance Evaluation of Robots in Flexible Manufacturing Cells
	Benhabib, B.	Automation	\$ 118,400	Sensory-based Automation/Analysis and Design of Industrial Robots
	Goldenberg, A.	Automation	\$ 455,800	Force and Impedance Control and Mechanics and Control of Dexterous Devices
	Woodhams, R.	Process	\$ 236,800	Manufacturing of Ordered Polymeric Profiles by Extrusion Drawing
	Sethi, S.	Management	\$ 148,600	Production Planning, Scheduling and Control of Manufacturing
	Turksen, I.	Management	\$ 166,000	Knowledge-based Management Systems for Integrated Manufacturing
	Meguid, S.A.	Design	\$ 173,300	Software Optimization & Integration in CIM Environment
TOTAL:			<u>\$1,661,500</u>	

APPENDIX 3

Chart 1

Federal Government Support

NSERC & Other - Year-to-Date Comparison

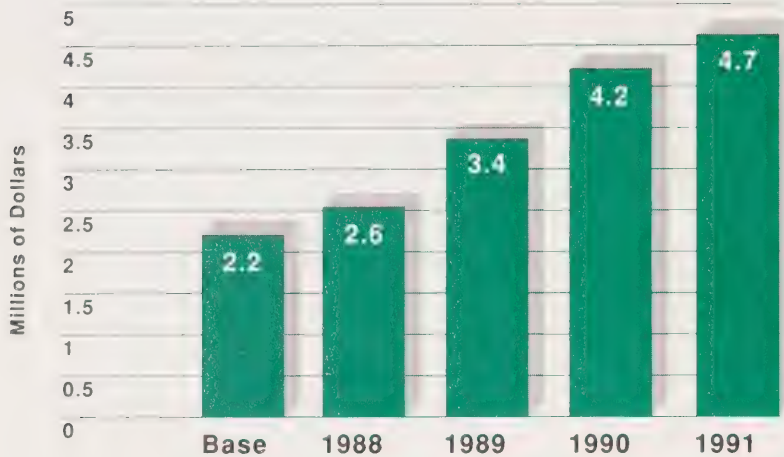
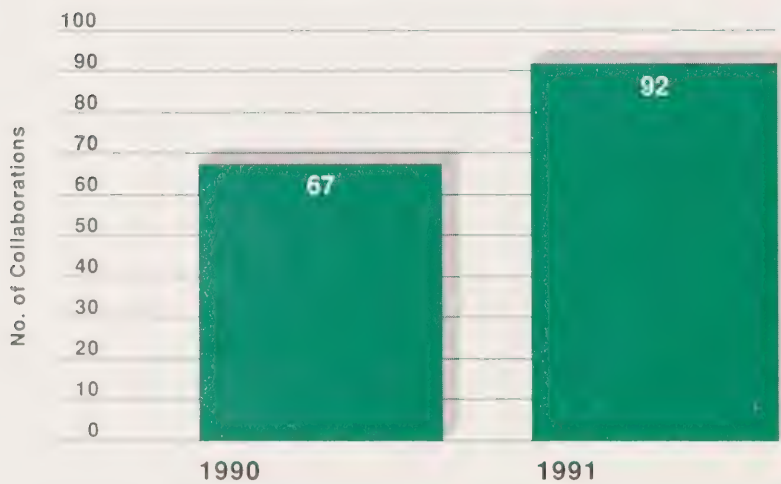


Chart 2

Principal Investigator / International Collaboration

Year-to-Date Comparison



APPENDIX 4

BASELINE DATA (SCHEDULE G)

EDUCATION: Graduate Students

Performance Measure	Base	Mar. 31/89	Mar. 31/90	Mar. 31/91	Mar. 31/92	Total
Total no. of graduate students registered	107	203	253	320	444	1,327
No. of above with visa				80	125	205
No. of students * leaving				71	97	168
No. of students * to Industry	22	30	44	65	55	216
No. of students * to Industry in Ontario				55	50	105
No. of students * to university positions				14	31	45

* Students with Studies beyond the Bachelor's degree.

Publications

Performance Measure	Base	Mar. 31/89	Mar. 31/90	Mar. 31/91	Mar. 31/92	Total
No. of refereed publication authorships	320	259	317	394	466	1,756
No. of patents	12	1	2	10	16	41
No. of invited papers & lectures	133	147	179	206	216	881
No. of technology licenses to industry		1	3	11	14	29

SUPPORT Industry Support

Performance Measure	Base	Mar. 31/89	Mar. 31/90	Mar. 31/91	Mar. 31/92	Total
1. Industry funding to researcher	418,899	2,578,692	3,369,163	4,884,175	2,928,538	14,179,467
2. Industry funding in-kind to support research				582,000	1,964,000	2,546,000
3. In-kind funding by industry to Centre Mgmt.		50,000	130,000	300,000	52,000	532,000
4. Membership fees to the Centre					149,000	149,000

SUPPORT
Government Support

Performance Measure	Base	Mar. 31/89	Mar. 31/90	Mar. 31/91	Mar. 31/92	Total
1. NSERC	2,019,146	2,567,676	3,004,873	2,983,097	3,643,649	14,218,441
2. Other Federal	131,333	70,200	362,200	1,247,232	1,119,676	2,930,641
3. Ontario (not centres)	172,800	988,598	1,095,623	1,643,896	1,439,564	5,340,481
4. Other Government	246,000	643,960	1,026,000	1,111,500	1,021,378	4,048,838
5. Foundations, etc.	92,666	80,000	127,400	51,900	101,000	452,966

INTERACTIONS
Communications/Technology Transfer

Performance Measure	Base	Mar. 31/89	Mar. 31/90	Mar. 31/91	Mar. 31/92	Total
1. Number of person days of Company employees attend workshops/seminars		381	472	788	428	2,069
2. Number companies in a working relationship with Centre investigators						
a) Chair Support		2	2	2	3	9
b) Research Interactions	47	97	128	160	246	678
c) Contacts	13	23	33	53	371	493
d) Consulting fees	8	14	33	39	51	145
e) Grant & Donations	14	12	17	23	46	112

Collaboration

Performance Measure	Base	Mar. 31/89	Mar. 31/90	Mar. 31/91	Mar. 31/92	Total
1. Federal Centres of Excellence				15	16	31
2. Other Ontario Centres				7	16	23
3. Other Canadian				81	31	112
4. Other International				67	92	159


APPENDIX 5

AUDITORS' REPORT

March 31, 1992

To the Members of the

Manufacturing Research Corporation of Ontario

 We have audited the balance sheet of Manufacturing Research Corporation of Ontario as at March 31, 1992 and the statement of income, expenses and change in fund balance for the year then ended. These financial statements are the responsibility of the company's management. Our responsibility is to express an opinion on these financial statements based on our audit.

We conducted our audit in accordance with generally accepted auditing standards. Those standards require that we plan and perform an audit to obtain reasonable assurance whether the financial statements are free of material misstatement. An audit includes examining, on a test basis, evidence supporting the amounts and disclosures in the financial statements. An audit also includes assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation.

In our opinion, these financial statements present fairly, in all material respects, the financial position of the corporation as at March 31, 1992 and the results of its operations and the changes in its financial position for the year then ended in accordance with generally accepted accounting principles.



Kitchener, Canada,

June 12, 1992

Chartered Accountants

STATEMENT OF FINANCIAL POSITION

As at March 31

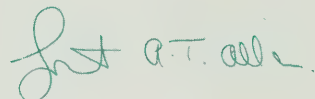
	1992	1991
	\$	\$
ASSETS		
Cash	70,564	6,981
Funds on deposit (note 3)	992,774	450,235
Accounts receivable	114,307	98,610
Due from University of Waterloo - interest	8,825	83,406
Advances to researchers	28,377	37,500
Prepaid rent	1,907	1,907
Fixed assets (note 5)	4,311,233	3,718,239
	5,527,987	4,396,878
LIABILITIES, EQUITY AND FUND BALANCES		
Accounts payable	685,258	146,663
Due to Formtech Inc. (note 4)	259,008	220,869
Deferred revenue	-	49,500
Equity in fixed assets (note 5)	4,311,233	3,718,239
Fund balance	272,488	261,607
	5,527,987	4,396,878

See accompanying notes

On behalf of the Board:



Director



Director

**STATEMENT OF INCOME, EXPENSES AND
CHANGE IN FUND BALANCE**

Year ended March 31

	1992 \$	1991 \$
INCOME		
Government grants (note 2)	6,462,000	6,239,300
Research contracts (note 7)	1,114,591	529,277
Interest income	132,513	187,721
	7,709,104	6,956,298
EXPENSES		
Salaries and benefits	3,451,520	3,235,112
Overhead	1,719,989	1,754,264
Direct operating	1,933,833	1,586,416
Capital	592,994	692,913
	7,698,336	7,268,705
Increase (Decrease) in fund balance from operations	10,768	(312,407)
Increase (Decrease) in fund balance from Baden-Wurttemberg project (note 8)	113	(13,290)
Increase (Decrease) in fund balance	10,881	(325,697)
Fund balance, beginning of year	261,607	587,304
Fund balance, end of year	272,488	261,607

See accompanying notes

NOTES TO THE FINANCIAL STATEMENTS

March 31, 1992

1

SUMMARY OF SIGNIFICANT ACCOUNTING POLICIES AND REPORTING PRACTICES

The Manufacturing Research Corporation of Ontario ["the Centre"] was incorporated on December 24, 1987 under the laws of Ontario as a not-for-profit corporation. The aim of the Centre is to foster long-term advanced research in manufacturing by universities and industry, and thus to enhance both knowledge and application of technology in order to help insure the future research and industrial competitiveness of the Province of Ontario in a global context. This research is performed in a cooperative venture between post-secondary educational institutions and industry. The Centre is managed independently of the universities and industries which have created, and are participating in, the work of the Centre.

The following summarizes the significant policies followed by the Centre:

Fund accounting

The accounts of the Centre have been maintained in accordance with the principles of fund accounting in order that limitations and restrictions placed on the use of available resources may be observed.

Accrual accounting

The accrual basis of accounting is followed whereby research and other expenses are recorded when incurred, and revenues when collected or when collection is virtually certain.

Fixed assets

Equipment purchases are expensed in the period in which payment is made.

The accumulated original cost of fixed assets, less any disposals, is recorded on the balance sheet; equity in fixed assets is recorded to the extent that asset acquisitions are currently funded or debt incurred to acquire such assets has been retired.

2

FUNDING OF THE CENTRE

The Province of Ontario is committed to make grants to the Centre of not more than \$31,000,000 over a period of five years on account of the program. The grants are to be provided quarterly, in accordance with the business plan submitted by the Centre. During the fiscal period ended March 31, 1992 the Centre received \$6,462,000.

NOTES TO THE FINANCIAL STATEMENTS cont'd

2

FUNDING OF THE CENTRE cont'd

Future funding from the Province of Ontario is contingent upon the Centre meeting certain criteria. Funding has been approved as follows:

	\$
Received to date	26,028,211
Subsequent funding schedule	
December 31, 1992	4,971,789
	31,000,000

The Province of Ontario has approved funding for an additional five year period to December 31, 1997. The level of funding has not yet been determined.

The amount of the unexpended portion of the Provincial grants which may be utilized in any subsequent operating period shall not exceed the following:

End of operating period	% of period allocation
5	5
6	0

3

FUNDS ON DEPOSIT

Funds on deposit are held by the University of Waterloo on behalf of the Centre. The University of Waterloo pays the Centre interest at the average monthly rate of return earned on the University's short-term investments.

4

MANAGEMENT CONTRACTS

The Centre manages the business affairs of Formtech Inc., an industry consortium formed to conduct research in the field of metal stamping. In return for this service the Centre is paid \$100,000 per annum which is reflected in revenue from research contracts. The banking activities of Formtech Inc. are conducted through the Centre which has resulted in a balance payable to Formtech Inc. at the year-end. Formtech Inc. transactions are not otherwise recorded in the Centre's financial statements.

5

FIXED ASSETS

All equipment or other assets purchased with any part of the Provincial grants shall be the property of the Centre. Upon termination of the Centre or if the agreement with the Government of Ontario is terminated prior to December 31, 1992, the ownership of the assets transfers to the Government of Ontario. Participants in the Centre shall have an option to acquire the assets at fair market value at that time.

6**CONTRACT RESEARCH -
UNIVERSITIES**

The Centre subcontracts research performed on its behalf to faculty members of the universities of Toronto, Western, Waterloo, McMaster, Queens and Carleton. Salaries expense represents administrative salaries, reimbursement to participating universities for the cost of incremental personnel directly involved and working in the research programme of the Centre, and the costs to purchase release time from teaching duties in order to free additional time for personnel to dedicate to the programme. Overhead is generally charged at a rate of 65% of salaries and benefits by the participating universities; such charge is meant to recover both the general university costs of the research programme, and the incremental cost of providing general infrastructure support at the academic unit level. Academic units of the universities are required to utilize 24% of the overhead charge as a research grant for the enrichment of the Centre's research programme.

7**RESEARCH CONTRACTS -
INDUSTRY**

The Centre enters into research contracts with the corporate sector including both individual companies and industry consortia. The revenues earned from this research are paid directly by industry.

8**BADEN-WURTTENBERG PROJECT**

The Manufacturing Research Corporation of Ontario entered into an agreement with the Province of Ontario effective January 1, 1990 which states that the Province is to provide additional funding to the Manufacturing Research Corporation of Ontario in the amount of \$690,000 over a 3 year period. This funding is to be used for the Computer-Aided Process Planning/Production and Control Integration Project which has as its major objective the improvement in the implementation of Computer Integrated Manufacturing. The research is to be conducted in conjunction with the Fraunhofer Institute for Production Automation of the State of Baden-Wurttemberg, Germany. The agreement between the Fraunhofer Institute for Production Automation and the State of Baden - Wurttemberg is similar to the agreement between the Manufacturing Research Corporation of Ontario and the Province of Ontario and is for the same amount. Technology transfer will take place between the two companies, but no funds will be transferred.

8**BADEN-WURTTENBERG PROJECT**

cont'd

Future funding from the Province of Ontario is contingent upon the Project meeting certain criteria. Funding has been approved as follows:

Received to date	517,290
Subsequent funding schedule	
December 31, 1992	172,710
	<u>690,000</u>

The increase in fund balance from Baden-Wurttemberg Project is determined as follows:

	1992	1991
	\$	\$
Income		
Government grants	231,125	228,665
Interest	—	1,540
	231,125	230,205
Expenses		
Salaries and benefits	116,987	130,184
Overhead	82,263	86,401
Direct operating	31,762	21,086
Capital	—	5,824
	231,012	243,495

Increase (decrease) in fund balance from
Baden-Wurttemberg Project 113(13,290)

9**COMMITMENTS**

As at March 31, 1992, the Centre was committed to operating and capital expenditures in the amount of \$84,000.

10**STATEMENT OF CASH FLOWS**

A statement of cash flows has not been included in these financial statements as it is not considered to provide additional meaningful disclosure.



An Ontario Centre of Excellence
Supported by Ontario Technology Fund

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Oakville, Ontario L6M 2G2